ARKIV FÖR FYSIK Band 12 nr 18

Communicated 8 May 1957 by MANNE SIEGBAHN and BENGT EDLÉN

An investigation of the decay scheme of Ta^{182} by means of a coincidence scintillation spectrometer

By PER OLOF FRÖMAN and HANS RYDE

With 4 figures in the text

SUMMARY

The level scheme of W^{182} proposed by Murray *et al.* and refined by Alaga *et al.* is in its essential features confirmed by means of coincidence experiments. Gamma ray intensities differing somewhat from those by Murray *et al.* are also obtained.

I. Introduction

The radioactive isotope Ta^{182} which has a half-life of 111 days [1] decays by negative electron emission to W^{182}. The energies of the gamma rays following this beta decay have been accurately measured by Murray *et al.* [2] by means of a curved crystal spectrometer. Using spectroscopic combination methods these authors have also been able to propose a level scheme for the daughter nucleus W^{182}. In a recent paper by Alaga *et al.* [3] a classification of the energy levels of W^{182} into different rotational bands has been made according to the unified nuclear model. Cf. Fig. 1. It may be of some interest to lend further support to the level scheme of W^{182} by means of coincidence experiments. Some experiments of this kind have been made by Mihelich [4]. In the present paper we shall report a more complete coincidence investigation of the decay of Ta^{182}.

In our investigation we have used a coincidence scintillation spectrometer built by Johansson and Almquist [5]. In this apparatus there are two scintillation spectrometers (each one consisting of a crystal[1], a photomultiplier and an amplifier) which are connected to a coincidence circuit with a resolution $\sim 0.2\ \mu s$, the output pulses of which are used to intensify the sweep of an oscillograph. Furthermore, one of the spectrometers is connected to a single channel analyzer the output pulses of which trigger the sweep of the oscillograph, and the other spectrometer is connected to a pulse shaper from which the pulses are fed to the Y-plates of the oscillograph. By

---

[1] The two crystals in the coincidence spectrometer are placed at a distance of a few centimeters from each other. The gamma quanta which arise from Compton processes in any one of the crystals are hindered to enter the other crystal by means of a lead plate placed between the crystals.

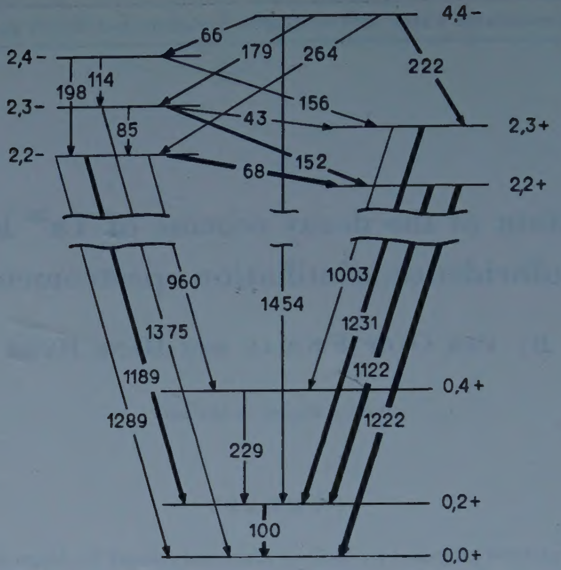


Fig. 1. The level scheme of W^{182} according to Alaga *et al.* [3]. The relative intensities of the gamma rays are indicated by the weights of the lines. For the strongly converted gamma rays of the energies 85 keV, 100 keV and 114 keV these weights do not indicate the corresponding total transition rates.

photographing the screen of the oscillograph one records those pulses which arise from gamma rays in coincidence with the radiation which gives rise to those pulses that are selected by the above mentioned single channel analyzer.

The density of the spectrum on the photographic film was measured with a micro-photometer, and the photometer trace obtained in this way was converted into relative intensity (i.e., relative number of pulses) by means of the characteristic curve for the photographic film. This curve was obtained by photographing different numbers of sweeps on the screen of the oscillograph, when the intensifying coincidence circuit and the sweep of the oscillograph were triggered by a pulse generator of known frequency. To simulate the fairly broad distribution of pulses corresponding to a gamma ray, an AC voltage of suitable amplitude was simultaneously imposed on the Y-plates. The frequency of this AC voltage was chosen in such a way that the different sweeps overlap at random. Exposures were made with different frequences of the pulse generator and with different exposure times. When the photographic densities of these films had been measured with the micro-photometer, the characteristic curve for the film could be obtained.

The radioactive tantalum material was obtained from Harwell, where it had been produced by the reaction $Ta^{181}(n,\gamma)Ta^{182}$. According to the manufacturers it contained no other radioactive isotopes but Ta^{182}. A solution of radioactive tantalum fluoride was obtained by dissolving a small piece of the irradiated tantalum metal in hydrofluoric acid. Radioactive sources were then prepared by allowing this solution to crystallize either on a small piece of perspex (to be used for the singles gamma spectrum and for the gamma-gamma coincidence spectra) or on a thin sheet of nylon of the same size as the crystals (to be used for the beta-gamma coincidence spectrum).

II. The singles gamma spectrum

The radioactive decay of Ta^{182} is accompanied by gamma rays arising from the deexcitation of the daughter nucleus W^{182}. When these gamma rays are present in their natural abundances, they give rise to a spectrum which will be referred to as a singles gamma spectrum. A spectrum of this kind is shown in Fig. 2. It has been obtained by means of a simple scintillation spectrometer consisting of a NaI(Tl) crystal ($\frac{3}{4}''$ thick and $1\frac{1}{2}''$ diameter), a photomultiplier, an amplifier and a single channel analyzer in which the width of the channel was chosen as small as was practically possible. The photo-peaks in the spectrum are distributed in mainly two groups, a lower one corresponding to gamma energies below 300 keV and an upper one corresponding to gamma energies between 1100 keV and 1250 keV. There exist also some gamma rays which have energies outside these two regions. Those which have energies above 1250 keV are weak, and those which have energies between 300 keV and 1100 keV are masked by the Compton distribution due to the strong gamma rays with energies in the region from 1100 keV to 1250 keV, even if they are not particularly weak. Therefore they cannot be seen in the singles spectrum in Fig. 2. A gamma ray with the energy 1003 keV appears, however, in a coincidence spectrum as will be discussed later.

By means of the scintillation spectrometer we have determined the relative intensities of those gamma rays which give rise to the most prominent peaks in the singles spectrum in Fig. 2. Our result indicated that the intensities reported by Murray *et al.* [2] may need some correction. In the present paper we shall tentatively use new intensity values which we obtain by multiplying the intensities of Murray *et al.* [2] by a function which varies in a fairly smooth way with the gamma ray energy and which we choose such that it is equal to one at about 155 keV and that the new intensities shall agree with our intensities for those gamma rays (or groups of gamma rays) for which we have been able to determine the intensities. The relative intensities obtained in this way are given in Table 1, where the values which we have not determined directly are in parentheses.

The photo-efficiency of our scintillation spectrometer was calculated in a semi-empirical way, and the resulting efficiency curve was used in our determination of the relative intensities for the most prominent gamma rays in the regions below 300 keV and between 1100 keV and 1250 keV. To connect our intensity scales for these two energy regions we did not rely on our calculated efficiency curve but used another scintillation spectrometer which was calibrated empirically for intensity measurements and had been used with very satisfactory results. By means of this spectrometer we also checked our relative intensities within the low energy and high energy regions and found agreement within ten per cent. This check of our relative intensities indicates that they are good to better than 20% which is generally accepted as a limit for the accuracy of such measurements, but it is not completely excluded that the uncertainty may be somewhat larger.

To facilitate the discussion of the coincidence spectra which will be given in the following section we shall now describe some of the more essential features of the singles spectrum in Fig. 2.

The peak at about 65 keV is due to a strong gamma ray with the energy 68 keV, a much weaker gamma ray with the energy 66 keV and several X-rays with energies between 58 keV and 69 keV [6]. These X-rays arise because of internal K conversion of essentially the gamma rays of energies 100 keV, 85 keV and 114 keV, probably

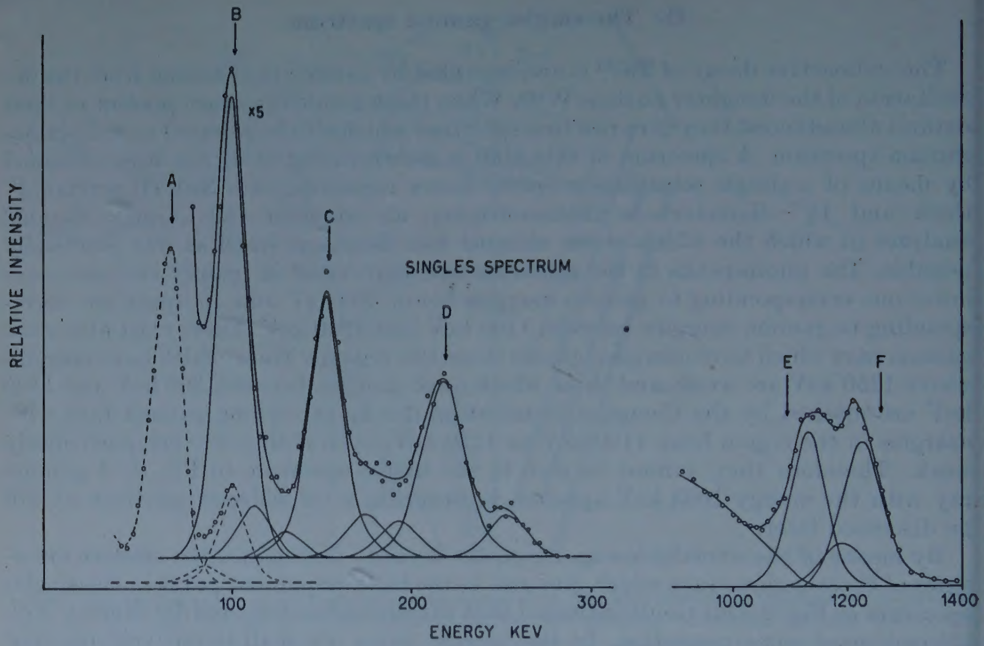


Fig. 2. The singles gamma spectrum of the gamma rays following the radioactive decay of Ta^{182}, obtained by means of a scintillation spectrometer with a single channel analyzer. The intensity scales in the regions below 300 keV and above 800 keV are chosen different from each other. The arrows indicate the positions of the channel in the different gamma-gamma coincidence spectra.

The spectrum has been resolved into separate photo-peaks, whose positions were known from the accurate gamma ray energies given by Murray *et al.* [2], and into a Compton distribution. In the low energy region the Compton distribution has more or less arbitrarily been chosen horizontal (and in the high energy region it may be somewhat underestimated). Because of the unavoidable uncertainty of the Compton distribution and of the shapes of the wings of the peaks arising from the strong gamma rays, the sizes of the small peaks corresponding to the weaker gamma rays are not particularly significant. In so far as the small peak at about 130 keV is significant, it represents an addition peak arising from gamma rays and X-rays of approximately half this energy.

contributing in this order. By comparing the intensities obtained by Murray *et al.* [2] with those obtained directly by us we are led to assume that the total intensity af all the X-rays is of the same order of magnitude as the intensity of the 68 keV gamma ray.

The peak at 100 keV is due to a single gamma ray of this energy.

The peak at about 155 keV is due essentially to two gamma rays with the energies 152 keV and 156 keV. Furthermore the low-energy wing of a gamma ray having the energy 179 keV also contributes somewhat to this peak. The intensity of the 152 keV gamma ray is about twice that of each one of the gamma rays with the energies 156 keV and 179 keV which have roughly the same intensity.

The peak near 225 keV arises from two gamma rays with the energies 222 keV and 229 keV, the intensity of the former one being about twice that of the latter one. On the high energy side of this peak there is a bump which is due to a gamma ray of the energy 264 keV.

In the pulse height distribution between 1100 keV and 1250 keV, which arises from

Table 1

Energy (keV)	Relative intensity		Multipole order according to Alaga *et al.* [3]
58–69 (K X-rays)	260		
66			$M1$
68			$E1$
85		(8)	$M1$
100	62		$E2$
114		(10)	$M1$
152	47	(35)	$E1$
156		(12)	$E1$
179		(15)	$E2+M1$
198		(7)	$E2$
222	47	(30)	$E1$
229		(17)	$E2$
264	14		$E2$
960			$E3$ $(+M2)$
1003			$E2$ $(+M1)$
1122	120		$E2$ $(+M1)$
1189	∼25		$E3$ $+M2$
1222	135	(90)	$E2$ $(+M1)$
1231		(45)	$E2$ $(+M1)$

photo-absorption of high energy gamma rays, the peak at about 1120 keV is due to a single gamma ray with the energy 1122 keV, whereas the peak at about 1225 keV is due to three gamma rays with the energies 1189 keV, 1222 keV and 1231 keV which together have an intensity which is slightly larger than that of the 1122 keV gamma ray. The intensity of the 1222 keV gamma ray is about twice that of the 1231 keV gamma ray, and the intensities of the 1189 keV and 1231 keV gamma rays are of the same order of magnitude. The Compton processes due to gamma rays in the high energy region give rise to the broad peak below 1000 keV. The photo-absorption of the previously mentioned gamma ray with the energy 1003 keV also contributes somewhat to this broad peak.

III. The coincidence spectra

In all our coincidence experiments the strength of the source, the solid angles and the exposure time were chosen such that a total number of at least ten thousand coincidence pulses were recorded, and that the number of accidental coincidences was at most ten per cent of the number of true coincidences.

When gamma-gamma coincidences were recorded, NaI(Tl) crystals were used in both the detectors of the coincidence scintillation spectrometer. When recording beta-gamma coincidences, we used an anthracen crystal in the detector which feeds pulses to the pulse height analyzer triggering the sweep of the oscillograph, whereas we used a NaI(Tl) crystal in the detector which feeds pulses to the Y-plates of the oscillograph.

The energy calibration of every coincidence spectrum was derived from that of singles spectra obtained photographically on the oscillograph screen before and after the exposure of the coincidence spectrum. Because of the long exposure time for the coincidence spectrum compared with the exposure times for the singles spectra, there is a certain broadening of the pulse height distribution in the coincidence spectrum. For our purpose this broadening is of importance only in the energy region around and above 1000 keV, and there a correction has been applied to the original energy calibration of the coincidence spectra. This correction was obtained from a comparison of all our coincidence spectra with a singles spectrum. In the regions below 300 keV and between 1100 keV and 1250 keV the final energy calibration is correct to within about three per cent. Those displacements of the peaks in the coincidence spectra relative to those in the singles spectrum that are only of this order of magnitude are not relevant.

The resolving power for the coincidence spectra obtained photographically on the oscillograph screen is somewhat better than that for a singles spectrum obtained by means of a scintillation spectrometer with a single channel analyzer. This fact should be kept in mind when comparing the coincidence and singles spectra. In this connection we also remark that the coincidence circuit may give rise to some uncertainties for the intensities in the coincidence spectra.

Every whole coincidence spectrum was obtained from three films covering the energy ranges 40–120 keV, 80–300 keV and 800–1400 keV. The intensity scales in the first two energy regions were joined by means of the height of the 100 keV peak. In the figures showing the coincidence spectra the intensity scales for the regions 0–300 keV and 1100–1250 keV have been chosen independently of each other, and the intensity scales for different coincidence spectra are not related to the absolute densities of the photographic films.

A. *The gamma rays which are in coincidence with the rays giving rise to the peak at about 65 keV in the singles spectrum*

The coincidence spectrum shown in Fig. 3A is obtained when gamma rays with the energies 68 keV or 66 keV or X-rays with energies in the region around 65 keV enter the channel of the analyzer in the coincidence spectrometer. The X-rays in this energy region are due to internal K conversion of essentially the gamma rays with the energies 100 keV, 85 keV (and 114 keV). The intensities in Table 1 and the internal K conversion coefficients[1] given by Murray *et al.* [2] indicate that the gamma ray with the energy 68 keV has roughly the same intensity as the X-rays due to the internal K conversion of the 100 keV gamma ray and also roughly the same intensity as the X-rays arising from the internal K conversion of the two gamma rays with the energies 85 keV and 114 keV. Each one of these three groups of rays may therefore be expected to contribute about one third to the intensity of the peak at 65 keV in the singles spectrum. This conclusion depends, however, sensitively on the intensities and K conversion coefficients for the 85 keV and 114 keV gamma rays.

The enhancement in the coincidence spectrum of the 65 keV peak relative to the 100 keV peak is connected with the strong K conversion of the 100 keV, 85 keV and 114 keV gamma rays and their coincidence relations to each other and to the 68 keV gamma ray.

---

[1] Throughout the present paper we use the theoretical conversion coefficients given by the curves in the paper by Murray *et al.* [2]. According to recent calculations by Sliv and co-workers (published by the Academy of Sciences of the USSR, Moscow-Leningrad 1956) these conversion coefficients are, however, somewhat uncertain.

The reason for the depression in the coincidence spectrum of the peaks at 155 keV and 225 keV relative to the 100 keV peak is not quite clear but may be due to uncertainties in the adopted intensities and conversion coefficients (or to experimental uncertainties). The relative heights of the peaks at 155 keV, 179 keV, 225 keV and 264 keV in the coincidence spectrum are in reasonable agreement with the proposed level scheme, the intensities in Table 1 and the conversion coefficients given by Murray *et al.* [2].

In the pulse height distribution between 1100 keV and 1250 keV the coincidence spectrum shows a depression at about 1225 keV which may be understood from the proposed level scheme and our assumption that the 68 keV gamma ray, the internal K conversion of the 100 keV gamma ray and the internal K conversions of the 85 keV and 114 keV gamma rays together give roughly the same contributions to the intensity of the 65 keV peak in the singles spectrum.

B. *The gamma rays which are in coincidence with the 100 keV gamma ray*

Fig. 3B shows the coincidence spectrum which is obtained when the 100 keV gamma ray triggers the coincidence spectrometer.

The height of the 65 keV peak in the coincidence spectrum can be compared only with that of the strongly depressed 100 keV peak, for the very uncertain height of the latter peak has been used to obtain the intensity scale for the 65 keV peak. Therefore the relative heights of the 65 keV peak and e.g. the 225 keV peak in Fig. 3B are not significant.

The small peak at about 100 keV in the coincidence spectrum is due to accidental coincidences of the 100 keV gamma ray and possibly also to the 114 keV and 85 keV gamma rays which are to some degree in coincidence with the 100 keV gamma ray according to the level scheme in Fig. 1.

The peak at about 225 keV is enhanced compared with the peak at about 155 keV by an amount which is in agreement with the level scheme in Fig. 1 and the intensities in Table 1.

The bump due to the 264 keV gamma ray and the valley between the peaks at 155 keV and 225 keV, to the height of which the 179 keV gamma ray contributes, appear in the coincidence spectrum somewhat depressed relative to the 225 keV peak. Qualitatively such depressions are to be expected.

According to the proposed level scheme the gamma rays giving rise to the pulse height distribution between 1100 keV and 1250 keV should appear in the coincidence spectrum with the same relative abundances as in the singles spectrum, except for the 1222 keV gamma ray which should be missing. This prediction is seen to be qualitatively confirmed by the appearance of the high energy region of the coincidence spectrum.

C. *The gamma rays which are in coincidence with the gamma rays constituting the peak at about 155 keV in the singles spectrum*

The channel in the coincidence spectrometer was adjusted to allow only pulses corresponding to the 152 keV and 156 keV gamma rays to enter it. The coincidence spectrum thus obtained is shown in Fig. 3C.

The relative heights of the peaks at about 65 keV and at 100 keV are approximately the same in the coincidence spectrum as in the singles spectrum. This result is in rea-

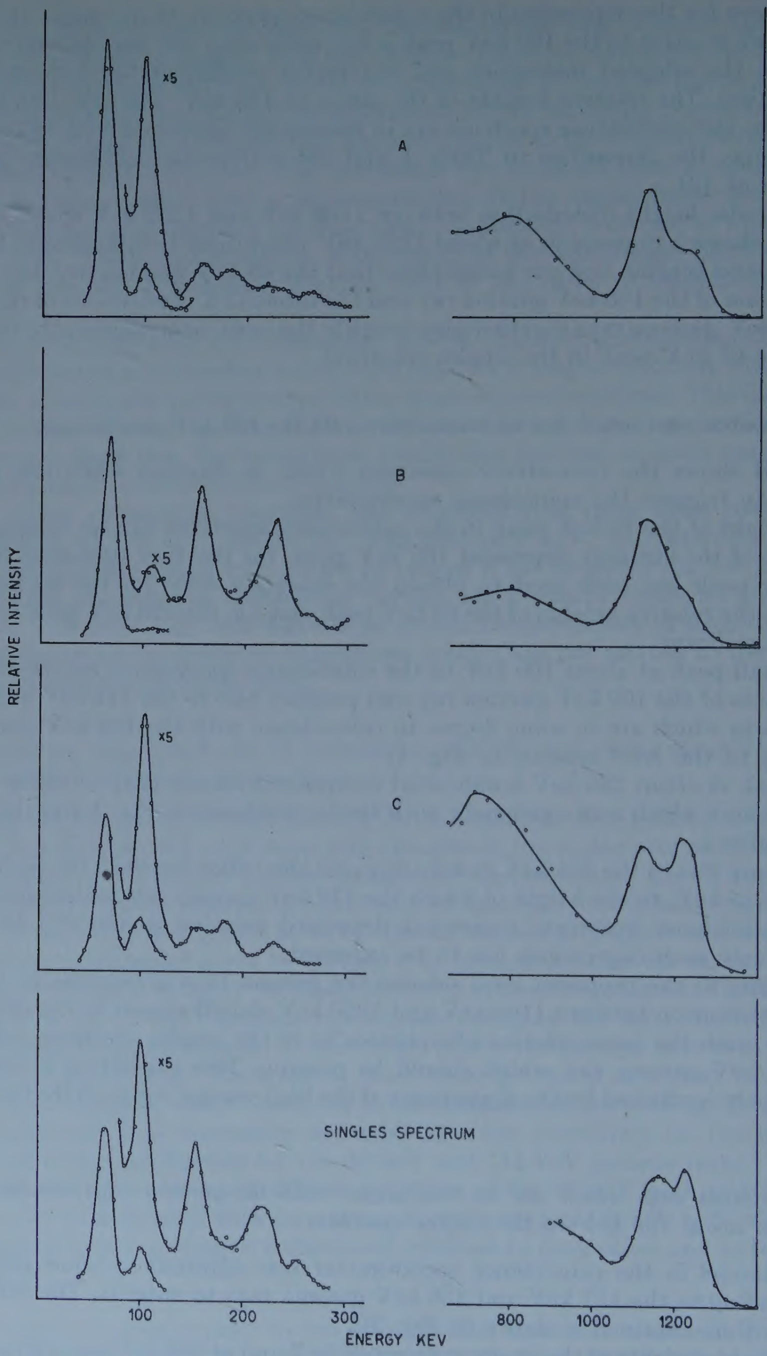
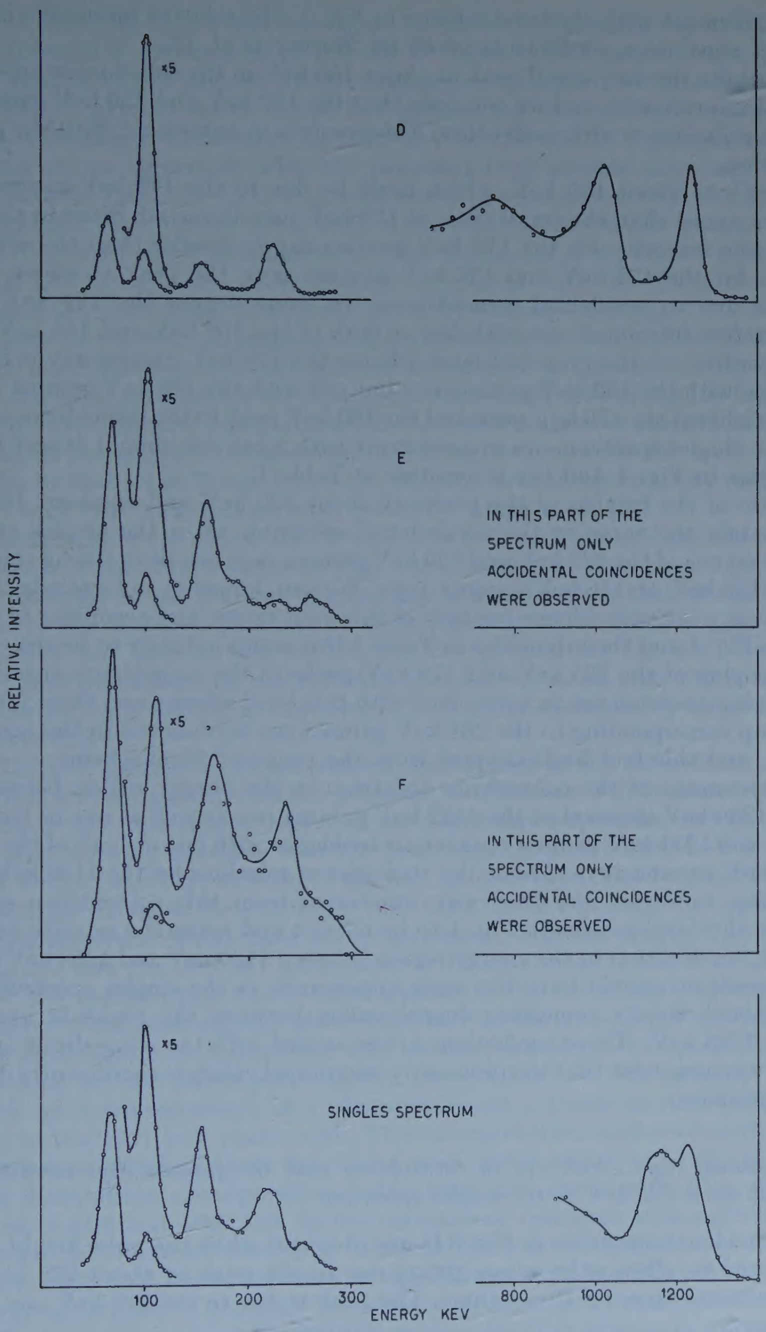


Fig. 3. Experimental results concerning



the gamma-gamma coincidences.

sonable agreement with the level scheme in Fig. 1, the relative intensities in Table 1 and the K conversion coefficients given by Murray *et al.* [2].

We attribute the very small peak at about 155 keV in the coincidence spectrum to accidental coincidences, and we conclude that the 152 keV and 156 keV gamma rays are not in coincidence with each other. This result is in agreement with the proposed level scheme.

The peak at about 180 keV, which must be due to the 179 keV gamma ray, is more pronounced than the small peak at 155 keV just discussed. Since in the singles spectrum the intensity for the 179 keV gamma ray is smaller than the sum of the intensities for the 152 keV and 156 keV gamma rays, the peak at about 180 keV cannot be due to accidental coincidences. To some degree the 179 keV gamma ray is therefore in coincidence with one or both of the 152 keV and 156 keV gamma rays. According to the proposed level scheme the 179 keV gamma ray is in fact in coincidence with the 152 keV gamma ray but not with the 156 keV gamma ray. The relative heights of the 179 keV peak and the 100 keV peak in the coincidence spectrum and in the singles spectrum are in agreement with what one should expect from the level scheme in Fig. 1 and the intensities in Table 1.

The ratio of the heights of the peaks at about 225 keV and at about 155 keV is approximately the same in the coincidence spectrum as in the singles spectrum. Therefore no one of the 222 keV and 229 keV gamma rays can be in strong coincidence with the 152 keV or 156 keV gamma rays. We can, however, not exclude the possibility that a weak coincidence relation of this kind exists, and according to the level scheme in Fig. 1 and the intensities in Table 1 this seems actually to be the case. The relative heights of the 225 keV and 179 keV peaks in the coincidence spectrum and in the singles spectrum are in agreement with this level scheme and these intensities.

No bump corresponding to the 264 keV gamma ray is observed in the coincidence spectrum, and this fact finds support from the proposed level scheme.

The appearance of the coincidence spectrum in the energy region between 1100 keV and 1250 keV shows that the 1122 keV gamma ray as well as one or both of the 1222 keV and 1231 keV gamma rays is in coincidence with one or both of the 152 keV and 156 keV gamma rays. About the coincidence relations for the 1189 keV gamma ray we can, however, not draw any conclusion from this coincidence spectrum. Assuming the level scheme in Fig. 1 to be correct and using the relative intensities in Table 1, we find that in the energy region between 1100 keV and 1250 keV the coincidence spectrum should have the same appearance as the singles spectrum except that it should show a somewhat deeper valley between the peaks at about 1125 keV and 1225 keV. These predictions are in accord with the coincidence spectrum, although we cannot say that the previously mentioned valley is significantly depressed in this spectrum.

D. *The gamma rays which are in coincidence with the gamma rays constituting the peak at about 225 keV in the singles spectrum*

The coincidence spectrum in Fig. 3 D was obtained when the pulse height analyzer was adjusted to allow only pulses giving rise to the peak at about 225 keV in the singles spectrum to enter the channel. The peak is due to the 222 keV and 229 keV gamma rays.

Compared with the peak at 100 keV, the peak at about 65 keV is in the coincidence spectrum depressed by a factor somewhat larger than two. In the singles spectrum the peak at about 65 keV is due essentially to the 68 keV gamma ray and to X-rays from the internal K conversions of the 100 keV and 85 keV gamma rays. Since the 100 keV gamma ray is present in the coincidence spectrum, we therefore conclude that the 68 keV gamma ray or the 85 keV gamma ray or both these rays cannot be in strong coincidence with either the 222 keV or the 229 keV gamma ray. These conclusions are in agreement with the proposed level scheme according to which neither the 68 keV nor the 85 keV gamma ray is in coincidence with the 222 keV or 229 keV gamma rays, except for a weak coincidence of the 85 keV gamma ray with the 229 keV gamma ray. The magnitude of the depression of the 65 keV peak relative to the 100 keV peak is also in qualitative agreement with the intensities given in Table 1 and the conversion coefficients given by Murray *et al.* [2].

The reason for the slight depression in the coincidence spectrum of the 225 keV peak relative to the 100 keV peak is not quite clear but may be associated with the uncertainty in the value adopted for the total conversion coefficient of the 100 keV gamma ray or with experimental uncertainties. The relative heights of the 155 keV and 225 keV peaks in the coincidence spectrum are in agreement with the level scheme in Fig. 1, the intensities in Table 1 and the reduced branching intensity ratio for the 1003 keV and 1231 keV gamma rays given by Alaga *et al.* [3].

In the coincidence spectrum the 179 keV, 198 keV and 264 keV gamma rays seem to be absent. If the level scheme in Fig. 1 is assumed to be correct, this indicates that the intensity of the 960 keV gamma ray is smaller than that of the 1003 keV gamma ray. The 960 keV gamma ray should in fact have much smaller intensity than the 1003 keV gamma ray, for the 960 keV gamma ray has been classified as an $E3$ $(+M2)$ transition and the 1003 keV gamma ray as an $E2$ $(+M1)$ transition, and furthermore the feeding to the level $(2,2-)$ is not considerably larger than that to the level $(2,3+)$.

The 1122 keV gamma ray does certainly not appear in the coincidence spectrum, and this fact is in agreement with the proposed level scheme. Furthermore, the energy calibration in the high energy region of our coincidence spectrum is very probably so good that we may conclude that the peak slightly above 1200 keV is due only to one or both of the 1222 keV and 1231 keV gamma rays. The symmetric shape of this peak then excludes the possibility that the 1189 keV gamma ray appears in the coincidence spectrum. These facts are in agreement with the proposed level scheme, according to which the 1231 keV gamma ray is the only one of the 1189 keV, 1222 keV and 1231 keV gamma rays that should appear in the coincidence spectrum.

The shape of the peak slightly above 1000 keV in the coincidence spectrum shows that this peak cannot be interpreted only as the peak of the Compton distribution corresponding to the photo-peak slightly above 1200 keV. We interpret the 1000 keV peak as a superposition of a photo-peak and a Compton distribution corresponding to the 1231 keV photo-peak. This interpretation is also supported by the fact that below 1000 keV there is a broad peak which seems to be the peak of the Compton distribution corresponding to the 1000 keV photo-peak. The presence of a photo-peak at about 1000 keV in the coincidence spectrum is in agreement with the proposed level scheme according to which there is one gamma ray at 960 keV and one at 1003 keV which are both in coincidence with the 229 keV gamma ray. The energy calibration is probably sufficiently good for us to conclude that it is the 1003 keV gamma ray and not the 960 keV gamma ray that appears in the coincidence spectrum. If the level scheme in Fig. 1 is supposed to be correct, this result shows that the intensity of the 960 keV gamma ray is much smaller than that of the 1003 keV gamma ray. We remark that we have previously arrived at the same conclusion in a quite different way. By resolving the pulse height distribution in the high energy region of the coincidence spectrum into photo-peaks at 1231 keV and 1003 keV and their corresponding Compton distributions one finds by means of the photo-efficiency curve for the crystal a rough value for the intensity ratio of these two gamma rays. The order of magnitude of this value is in agreement with the value obtained from the theoretical reduced branching ratio given by Alaga *et al.* [3] for the 1003 keV and 1231 keV gamma rays.

E. *The gamma rays which are in coincidence with the 1122 keV gamma ray*

The pulse height analyzer was adjusted to allow only pulses corresponding to energies slightly less than 1100 keV to enter the channel. These pulses arise almost exclusively from the 1122 keV gamma ray. The coincidence spectrum obtained in this way is shown in Fig. 3E.

The intensity ratio for the peaks at about 65 keV and at 100 keV is slightly enlarged (or almost the same) in the coincidence spectrum as in the singles spectrum. This fact is in good agreement with the predictions obtained from the level scheme in Fig. 1, the gamma ray intensities given in Table 1 and the conversion coefficients given by Murray *et al.* [2].

Assuming the proposed level scheme to be correct and using the intensities in Table 1 we may expect the ratio of the heights of the 100 keV and 155 keV peaks to be approximately the same in the coincidence spectrum as in the singles spectrum. This prediction is confirmed by Fig. 3E.

On the high energy side of the 155 keV peak there is a marked bump in the coincidence spectrum. It is very natural to attribute this bump to the 179 keV gamma ray. According to the level scheme in Fig. 1 and the intensities in Table 1 we expect such a bump due to the 179 keV gamma ray and of roughly the same magnitude as is actually found.

The peak at about 225 keV is strongly depressed in the coincidence spectrum, and this fact is in complete agreement with the proposed level scheme according to which the 222 keV and 229 keV gamma rays are not in coincidence with the 1122 keV gamma ray.

In the coincidence spectrum there appears clearly a peak that must be due to the 264 keV gamma ray. To a certain degree this gamma ray is therefore in coincidence with the 1122 keV gamma ray. This result is in agreement with the proposed level scheme. The fact that the heights of the 264 keV and 155 keV peaks have approximately the same ratio in the coincidence spectrum as in the singles spectrum is also in agreement with this level scheme and the intensities given in Table 1.

In the region between 1100 keV and 1250 keV the number of (both true and accidental) coincidence pulses was found to be of the same order as the number of accidental coincidence pulses. Therefore we conclude that no gamma rays with energies in this region are in coincidence with the 1122 keV gamma ray. This conclusion, which is obviously in agreement with the proposed level scheme, is also supported by the fact that in the coincidence spectrum there does not seem to appear any appreciable Compton distribution above the peak which is due to the 264 keV gamma ray.

F. *The gamma rays which are in coincidence with the 1222 keV or 1231 keV gamma rays*

The coincidence spectrometer was gated with pulses lying on the high energy descent of the 1225 keV peak. In this way we selected those gamma rays which are in coincidence with the 1222 keV or 1231 keV gamma rays. The coincidence spectrum is shown in Fig. 3F. The counting rate for the trigger pulses was low, and therefore the photographic film from which the coincidence spectrum was obtained showed a low photographic density with comparatively large statistical fluctuations, especially in the energy region between 100 keV and 300 keV. Therefore and also because of the uncertainty of the characteristic curve for the photographic film at low photographic densities this coincidence spectrum can be used only in a very qualitative way.

The enhancement in the coincidence spectrum of the 65 keV peak relative to the 100 keV peak is in agreement with what we may expect from the level scheme in Fig. 1 and the intensities in Table 1.

The presence of the 155 keV and 225 keV peaks in the coincidence spectrum in proportions that are of similar order of magnitude as in the singles spectrum is also qualitatively consistent with what we may expect, but these two peaks are not so much enhanced relative to the 100 keV peak as one should expect from the intensities in Table 1 and the conversion coefficients given by Murray *et al.* [2]. The reason for this may be due to experimental uncertainties.

No high energy gamma rays were found to be in coincidence with those triggering the coincidence spectrometer. This result also fits into the scheme.

G. *Beta-gamma coincidence spectrum*

It is known that the beta spectrum of Ta^{182} has a maximum energy of about 0.5 MeV, but it has not been possible to resolve this spectrum into its separate beta components [1]. Despite of the incomplete knowledge about this beta spectrum one may obtain some information about the level scheme of W^{182} by studying beta-gamma coincidences in the decay of Ta^{182}. For this purpose the position and the width of the channel in the pulse height analyzer, which in this case receives pulses from an anthracen crystal detector, are best chosen such that the analyzer selects preferably the most energetic beta components. To reduce the relative amount of back-ground of gamma-gamma coincidences due to Compton absorption of the high energy gamma quanta in the anthracen crystal and also to get a sufficiently high coincidence counting rate it is desirable to set the channel sufficiently much below the endpoint of the beta spectrum, but at the same time care should be taken that the low-energetic beta components shall not enter the channel appreciably. The channel was adjusted such as to fulfil as well as possible these two contradictory requirements, and then the channel seemed to accept electrons of energies lying roughly between 0.25 MeV and 0.35 MeV. Therefore it was expected that the beta component to the level (4,4 −) was essentially excluded from entering the channel while the other beta components preferred to enter it in proportions that increased rapidly with the energies of the beta components. The coincidence spectrum thus obtained is shown in Fig. 4*a*. The exposure was then repeated with the same exposure time and the same geometry but with the only change that a beta absorber of perspex (2.0 mm thick) was placed between the radioactive source and the anthracen crystal. In this way we obtained a coincidence spectrum showing the gamma rays that are in coincidence with the Compton back-ground mentioned above[1]. This coincidence spectrum is shown in Fig. 4*b* where the relative intensity scales are the same as in Fig. 4*a*. By subtracting the spectrum in Fig. 4*b* from that in Fig. 4*a* we obtain a pure beta-gamma

---

[1] The secondary effects in the perspex absorber are expected to be fairly unimportant.

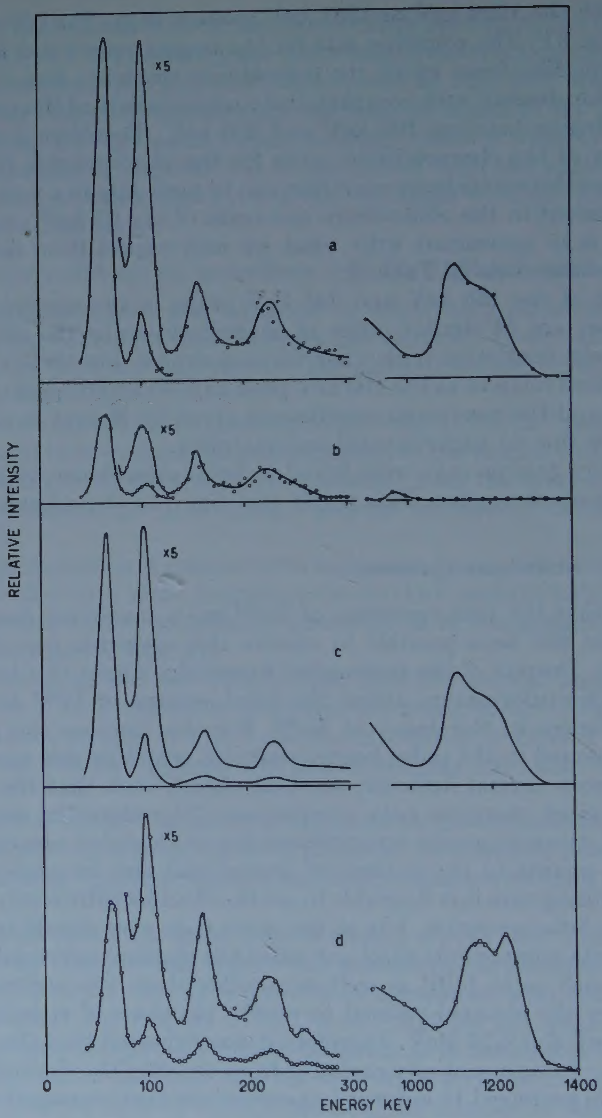


Fig. 4. Experimental results concerning the beta-gamma coincidences.

coincidence spectrum. This spectrum, shown in Fig. 4*c*, will in the following be referred to simply as the beta-gamma coincidence spectrum. It is to be compared with the singles gamma spectrum in Fig. 4*d*.

The fact that the Compton distribution is present in Fig. 4*a* but not in Fig. 4*b* shows that one or more of the beta components selected by the channel are in coincidence with one or more of the gamma rays in the high energy region and that no high-energetic gamma rays of appreciable intensities are in coincidence with each other.

The last one of these two conclusions was drawn already in our study of the gamma-gamma coincidences.

The enchancement in the beta-gamma coincidence spectrum of the 65 keV peak relative to the 100 keV peak is in agreement with the suggestion by Murray *et al.* [2] that the beta components feed only the levels with excitation energies above 1 MeV in the level scheme of W^{182} and that the intensity of the beta component to the level (2,2 −) is larger than that of the beta component to the level (2,2 +). Part of this enhancement may also arise because a possible beta component to the level (2,3 −) might enter the channel to some extent.

In the beta-gamma coincidence spectrum the pulse height distribution in the region between 100 keV and 300 keV is much depressed with respect to the 100 keV peak. The slight presence of the 155 keV and 225 keV peaks may be due partly to accidental coincidences and partly to possible beta components to the levels (2,3 −) and (2,3 +). The very probable absence in the beta-gamma coincidence spectrum of a bump corresponding to the 264 keV gamma ray may be interpreted as supporting the proposed level scheme and as providing a check that the beta component feeding the level (4,4 −) did not enter the channel appreciably. According to the level scheme the 179 keV gamma ray should also be absent in the beta-gamma coincidence spectrum, and the appearance of this coincidence spectrum is consistent with this prediction.

In the high energy region of the beta-gamma coincidence spectrum there is a depression of the pulse height distribution at about 1225 keV. This fact is in agreement with the proposed level scheme according to which we may expect the 1231 keV gamma ray to be suppressed in our beta-gamma coincidence spectrum.

ACKNOWLEDGEMENTS

We express our sincere gratitude to Professor S. von Friesen for placing good experimental facilities at our disposal. We are also indebted to Dr. S. A. E. Johansson who has given us good advice during the course of this work, and to Dr. L. Stigmark whose help with the electronics has been invaluable.

Department of Physics, University of Lund, Lund, Sweden. September 1956.

REFERENCES

1. J. M. Hollander, I. Perlman, and G. T. Seaborg, Rev. Mod. Phys. *25*, 469 (1953).
2. J. J. Murray, F. Boehm, P. Marmier, and J. W. M. DuMond, Phys. Rev. *97*, 1007 (1955).
3. G. Alaga, K. Alder, A. Bohr, and B. R. Mottelson, Mat. Fys. Medd. Dan. Vid. Selsk. *29*, no. 9 (1955).
4. J. W. Mihelich, Phys. Rev. *95*, 626 (1954).
   —— Bull. Am. Phys. Soc. *29*, no. 4, 33 (1954).
5. S. A. E. Johansson and S. Almquist, Arkiv för Fysik, Bd. *5*, no. 20 (1952).
   S. A. E. Johansson, American report ISC-431 (1953).
   —— Phys. Rev. *100*, 835 (1955).
6. O. Beckman, Arkiv för Fysik, Bd. *9*, no. 32 (1955).

Tryckt den 14 augusti 1957

Uppsala 1957. Almqvist & Wiksells Boktryckeri AB